ANNOTATION

on the thesis of Aben Khairulla Khalidillauly "Development of the backfilling technology for mining of the reserves below the pit bottom and in the pit walls" for the PhD degree in major "6D070700 - Mining".

Gold is used by countries as an insurance and reserve fund. The recorded gold reserves are concentrated in the Central Banks and the insurance reserves, now account for more than 31 000 tonnes.

Today, production amounts of the precious metal have considerable inertia. Thus, the supply of mined gold, has a small variation on year-to-year basis and significantly lower than the supply of the scrap gold, gold sales by banks and investors.

According to the «NaturalResourceHoldings», there are 580 fairly large gold deposits in the world with total reserves of 3.72 billion.oz with an average grade of 1.01 grams of gold per ton of ore. These deposits belong to 312 companies, including public, private and government-owned corporations, 261 deposit owned by independent mining juniors.

Analysis of global trends in mining and exploration of gold deposits in the last 25 years shows there are active periods of both increases and decreases in gold production. Geographic structure of gold production in the world has changed dramatically over the past three decades. The largest producers today are China, Australia, Russia and the United States. Although the dollar price of gold on the market fell by 6% in 2015, in reality it has grown up in the currencies of 17 out of 20 top gold mining countries. Despite the significant drop in the price of gold in 2013, the volume of primary metal production continues to grow.

Intensive mining of the deposits in the last 20-25 years has led to the depletion of reserves with favorable geological conditions. With the increasing depth of the development, worsening mining and geological conditions, reduction of the grades of metals, more stringent environmental requirements, and etc., there is the problem of finding more effective ways of mining.

There are more than 2 thousand deposits in the world today, which are transitioning or will transition from open-pit to underground mining. In the last 10 years, the number of such deposits has increased almost 1.5 times, mainly because pits are reaching their ultimate depths and the remaining reserves of deeper horizons can only be mined using underground mining methods. During the transition from open pit to underground, there is an ore pillar left between the two operations. Subsequent mining of this pillar using will inevitably lead not only to heavy losses and ore dilution, but also a variety of processes and issues, which are practically impossible to predict and calculate.

At the same time, there are reserves left at the bottom and walls of the pit, which are not feasible to mine with the open pit.

There is a limited number of research works in this area and significant results were obtained in a few individual cases.

Therefore, this study on the technology of mining of reserves below the pit and in the pit walls is a critical task.

Objective- Development of the technology of mining of the reserves below the pit bottom and in the pit walls, providing the most complete extraction of reserves, safety, economic and ecological efficiency of mining operations.

Work idea is the application of stages of mining of the reserves below the pit bottom and in the pit walls with the backfill of different strength and rational blasting parameters in the discharge zones.

Research object is Maykain gold mine, which is situated in Bayanaulsky area of Pavlodar oblast, and a typical mine with an open-pit to underground transition.

Subject is the Research of the technology of mining of the reserves below the pit bottom and in the pit walls.

Research Objectives:

• analysis of the technical situation and the experience of mining of the reserves below the pit bottom and in the pit walls;

• development of the technology of mining of the reserves below the pit bottom using mining methods with backfill;

• establishment of a rational composition of the filling mixture from mining waste or tailings considering mining conditions to provide sustainable artificial backfilled massif with accordance to the stages of the stopes;

• justification of blasting parameters at the contact "ore-backfill", which reduces backfill destruction;

• economic evaluation of the proposed technical solutions.

The scientific novelty of the work:

- dependence of the necessary strength of backfilling mass from the height of the stope opening and the stage of the stope mining was established;
- influence of additives-plasticizers on the rheological characteristics of the hardening mixtures was obtained;
- undercharged portion of the drill holes at their bottom in the blast hole rings at the contact with backfilled stopes was determined to depend on the length of the discharge zone and uniformity of the explosives distribution. Undercharging will reduce the ore dilution and damaging of the backfill.

In carrying out this work a complex method of research was used. It includes analysis and scientific generalization of research and technical information and practice of mining industry, experimental studies, statistical processing and calculations, economical evaluation of the technical decisions taken.

Scientific position:

- strength of the backfill is determined considering stope mining stages and heights of the openings of the stopes;
- chemical additives-plasticizers improve the rheological characteristics of filling mixes by increasing their mobility and strength characteristics, reducing the water contents in the mixtures;
-value of undercharge of ring drill holes in their bottom part at the contact with backfilled stopes to be determined depending on the length of the discharge zone, which reduces the breakage of backfill and ore dilution.

Practical value Development of the technology of mining of the reserves below the pit bottom and in the pit walls using backfill with varying strength, and justification of blasting parameters at the ore-backfill contact.

Validity and reliability of scientific statements confirmed by the correct use of theoretical and experimental studies, representative volume and the convergence of the theoretical and experimental data.

Personal contribution of the author: analysis of foreign and domestic experience of mining of the under-pit reserves, development of mining technology of under-pit reserves; conduction of laboratory research to determine the composition of the filling mixture; justification of blasting parameters at the ore-backfill contact; definition of the technical and economic indicators of the proposed mining technology.

Testing of work: results were presented at an international scientific conference "Innovative development of the mining sector" "(Krivoy Rog, 2016), International Baikonurov readings (Zhezkazgan, 2015) and International Satpayev readings (Almaty, 2017).

Publications include three articles in the "Mining Journal of Kazakhstan", Scientific and technical collection "Blasting" (Moscow, 2017), as well as in the "Mining Journal" (included in the Scopus base) (Moscow, 2017).

The structure and scope of work: Dissertation includes introduction, 4 chapters, conclusion, 52 bibliographic items and 106 typewritten pages, 55 figures, 18 tables.

The upper part of the deposit was mined out with an open pit, which reach the depth of 170 m, than the mine has transitioned to sublevel caving underground mining method.

During this, the mine started having following problems: collapse of the pillars, slide of the north-eastern pit wall, which led to the collapse of pillars between the blocks. It has further created difficulties for the mining of the ore reserves below the pit and in the pit walls. This resulted in disruption of the underground mine ventilation, pit water and precipitation water seepage from the pit and the surface. All this eventually led to complications in the extraction of ore, high dilution and increase in costs.

Given the geological conditions of the deposit, the proposal was to use sublevel stoping underground mining method with backfill. In this case the ore body is divided into sections along the strike with the length of 60 m. Vertically blocks are divided into three sublevels with the height of 17 m. Along the strike blocks are divided into 10 m wide stopes, across the strike they are divided depending on the thickness of the ore, so that the ratio of the width of the stope to the thickness does not exceed the value of 1:2. Preparation of the block consists of drifting the decline at an angle 8-12°, ventilation-backfill raise, transportation drifts and crosscuts at an angle of 5-6° for loading and hauling. Ore pass is sunk from the haulage level to the sublevels. Each crosscut is connected with the ventilation-backfill crosscuts, which are developed from the ventilation-backfill drifts. Further, loading bays, drill drifts, slot raises are developed. Production starts with cutting a slot raise and subsequent blasting of ore using blast hole charges. The diameter of the holes is 56-70 mm. Operating development is supported with bolts with shotcrete or steel arches of special profile depending on the stability of the host rock. Paste backfill is pumped into the mined out stopes using pipelines laid in backfilled excavations of the upper sublevel.

There are several stages of the stopes proposed for mining of the reserves below the pit bottom:

- first stage – mining of the stope reserves under the protection of block pillars, where the artificial pillar (filled stope) is loaded almost exclusively by its own weight;
- second stage - the stope is mined with full exposure of an artificial pillar (filled stope) on one side;
- third stage - the exposure of an artificial pillar on both sides.

The difference of this technology is that the stopes of different stage are filled with the mixture of different strength.

Based on studies, considering the geological conditions and the parameters of the stopes, it was determined that for the conditions of "Maikain" mine, the required strength of the artificial pillar depending on the stage of the stope and the area of its vertical exposure varies within 2,6-4,25 MPa and amounts to:

- stage I stopes - 2.6 MPa;
- stage II stopes - 3.0 MPa;
- stage III stopes - 4.25 MPa.

Necessary strength of the artificial pillar depending on the stability conditions with a specific vertical exposure (Table 1)

Table 1 – Dependence of the required backfill strength on the stope vertical exposure

Stope vertical exposure (mean value), m	Required strength, MPa
10.5 (7.5)	1.2
10-15 (12.5)	1.5
15-20 (17.5)	2.0
20-30 (25)	2.5
30-40 (35)	3.0
greater than 40 (45)	4.0

Data was obtained by processing the strength characteristics required verses the height of the stope (vertical exposure) (Figure 1)

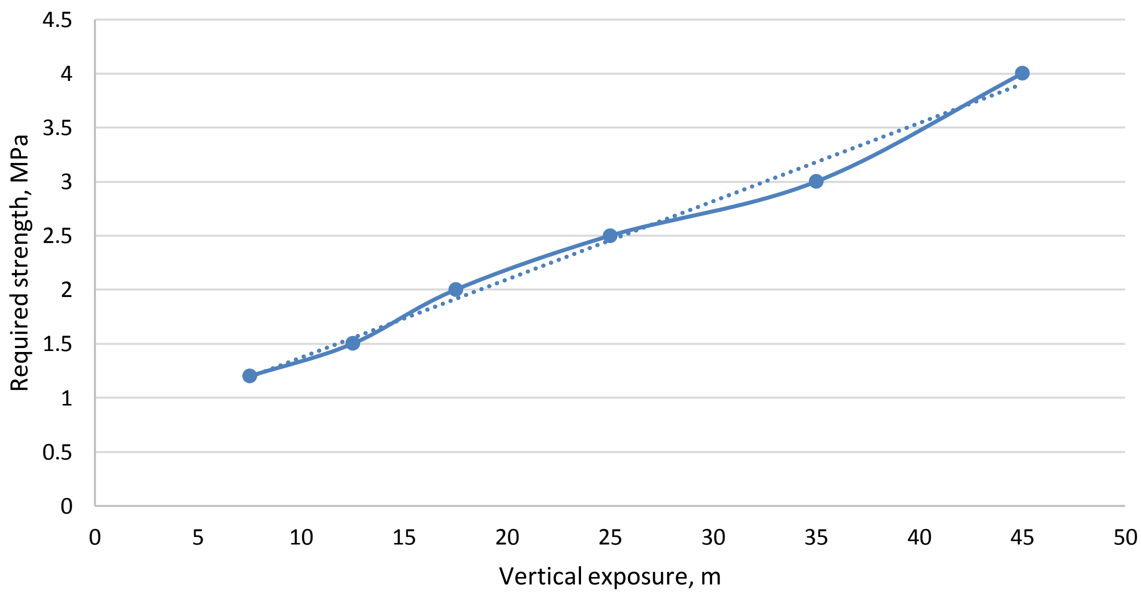


Figure 1 - Dependence of the required backfill strength from the stope height (vertical exposure)

Dependence can be displayed as a formula:

$$\delta = 0.07H + 0.65$$
$$5 < H < 45$$

where δ - required backfill strength, MPa, H – stope height (exposure), m.

In order to prepare a mixture with the above properties, which would give 12 to 14 cm mixture mobility and shear stress of 20 to 25 Pa, allowing its gravity transportation and required strength there were experiments conducted. To reduce the cost of preparation, it has been justified and suggested to mainly use locally available materials for the backfill. To do so, a research has been conducted on: flotation tailings; screenings of the crusher; rock from the drifting works, limestone of the "Keregetas" quarry.

The studies were carried out according to the following procedure. Theoretic calculation of the composition of the mixture following the criterion:

$$\frac{Ц}{\rho_Ц}+\frac{U}{\rho_u}+\frac{X}{\rho_x}+\frac{O}{\rho_o}+\frac{B}{\rho_b}=1,$$

где Ц- cement consumption, kg/m^3
U – lime consumption, kg/m^3
X – flotation tailings consumption, kg/m^3
O – consumption of screenings of the crusher, kg/m^3
B – water consumption, kg/m^3
$\rho_Ц$, ρ_u, ρ_x,ρ_o, ρ_b – respectively, the density of cement, lime, flotation tailings, screenings and water.

Given that currently the most common method of preparation of a back-filling mixture is a ball mill activation, it was adopted as a basis.

The laboratory mill was loaded with the components of the mixture and mixed for 5 minutes. Obtained mixture was tested for the mobility in the construction cone and the shear stresses on the Rebinder-Weiler instrument. Mixtures that met the mobility and shear stress requirements specified above were put in molds and after hardening were tested for strength at the age of 14, 28 and 90 days.

The composition of the tested mixtures differed in the ratio of the components, which subsequently made it possible to establish the dependence of the mobility, shear stress, and dynamics of the strength on the composition of the mixture.

Taking into account that the grains of the cement have a rather coarse grinding, and when they are milled in a ball mill, their regrind occurs, studies have been carried out on the effect of the fineness of cement grinding on the strength of the backfill, and it has been established experimentally that re-grinding of cement allows more complete utilization of its activity and, as a result, increases the strength of the resulting artificial pillar.

Backfill strength was determined in the laboratory by crushing test-samples using a hydraulic press (Figure 2). There were three samples prepared for each test. Standard terms of testing were 28 and 90 days. Size of the mold for the fill mixtures was 100 × 100 × 100 mm.

Results of experiments have shown that waste rock is not suitable for the preparation of the mixture, because the rock is not grindable in the mill and the mixture does not keep the water.

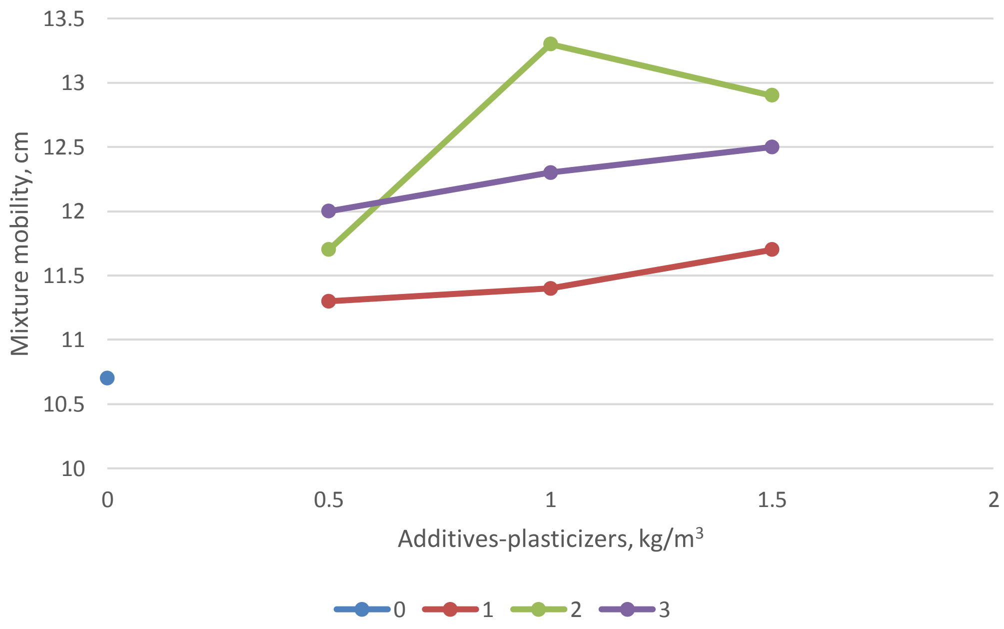
For conditions "Maikain" mine, it is proposed to use dry flotation tailings from the dump and screenings of the crusher.

Further studies have been directed to increase the strength, mobility of filling mixture and decrease material consumption. For these purposes, we have conducted a study on the effects of additives-plasticizers on the rheological properties of the mixtures.

There is a variety of different chemical additives produced worldwide and domestically. We have chosen PozzolithMR 25, 55 and 100 Pozzolith XR, which are liquid additives used to improve fluidity of the mixture. They contain no chlorine and used for obtaining homogeneous and high-quality concretes. Studies were conducted using three kinds of additives, wherein the amount of cement was 140 kg/m^3, tailings in the range of 1193-1389 kg/m^3; water 439-511 kg/m^3. The quantity of additives ranged from 0,5 kg/m^3 to 1.5 kg/m^3 with an increment of 0.5 kg/m^3.

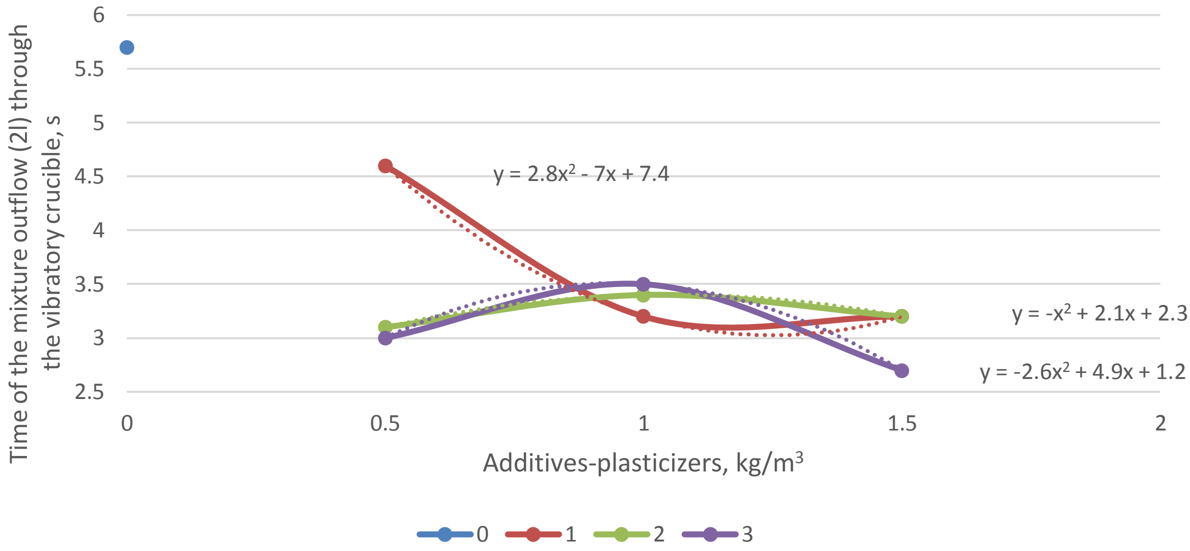
Mobility of the mixture was also determined by flow time of 2 liters of mixture out of vibratory crucible.

Data processing resulted in determining the dependence of the changes of the mobility of the filling mixture and the its outflow time from the vibratory crucible when the additives-plasticizers are used (composition of the mixture: cement - 140 kg/m^3, tailings - 1288 kg/m^3, and water - 476 kg/m^3, the ratio S:L in the tailings - 73:27, calculated density of the mixture -1904 g/l (figures 2,3).



0 - without additives; 1, 2, 3 - with additives-plasticizers, respectively, PozzolithMR 25, PozzolithMR 55 and Pozzolith 100 XR

Figure 2 - Change in filling mixture mobility with additives-plasticizers

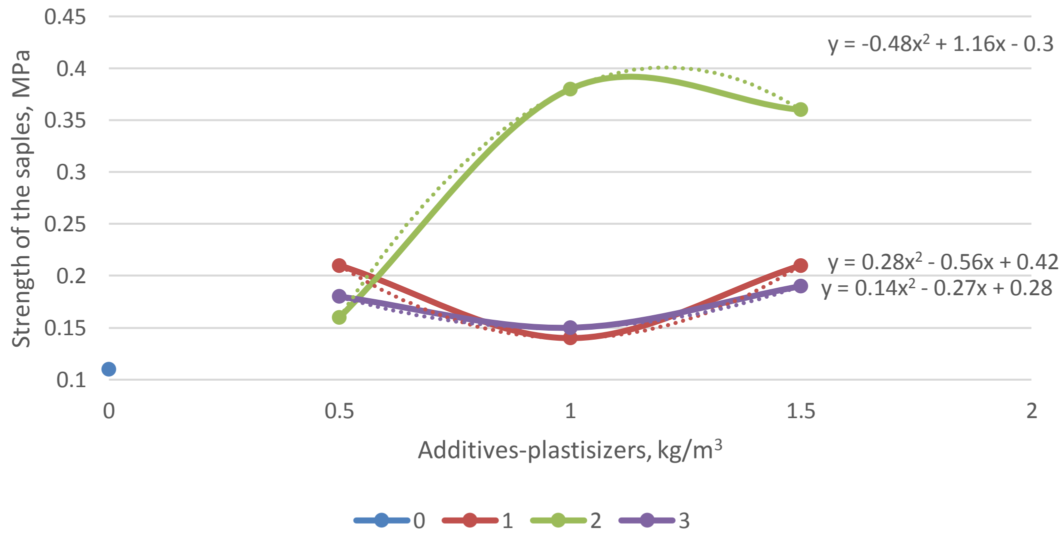


0 - without additives; 1, 2, 3 - with additives-plasticizers, respectively, PozzolithMR 25, PozzolithMR 55 and Pozzolith 100 XR

Figure 3 - Chang in the time of outflow of the filling mixture from the vibratory crucible

Increase in the mobility of the mixture due to the introduction of chemical additives can reduce the water content of the mixture, and this in turn leads to an increase in the strength of the hardened backfill massif.

For the purpose of analyzing the change in the strength of the resulting backfill massif several samples were tested for the standard uniaxial compression at the age of 14 and 28 days. (Figure 4).



0 - without additives; 1, 2, 3 - with additives-plasticizers, respectively, PozzolithMR 25, PozzolithMR 55 and Pozzolith 100 XR

Figure 4 - Change in the strength of samples of the backing mixture with the use of plasticizer additives at the age of 14 days

As a result of the research following mixture compositions were proposed for the conditions of the Maikain mine (table 2).

At the end of the laboratory studies, it was concluded that:

- the most appropriate additive to be used at the Maikain mine is chemical plasticizer PozzolithMR 55;
- use of the additive in the composition of filling mixture enables (depending on the quantity) to increase the mobility of the mixture for up to 20% in the laboratory conditions;
- strength of the backfill at the age of 28 days can be increased by 10-15% or in the case when the strength properties of the filling mass are kept at the same level, it can reduce the consumption of expensive cement.

As it is known, when using mining methods with backfill and blasting with rings, backfill mass can be damaged by the explosion. Many mines have experienced that ore dilution with backfill material results in a sharp decrease in the recovery of the metals at the processing plant. Sometimes loses due to reduced extraction at the processing plant may greatly exceed the full costs of the backfill.

Stress-strain state of a rock mass in the vicinity to the backfilled stope is formed depending on the direction of the maximum and minimum stresses. On the other hand, during the blasting operations of the rings at the ore-backfill contact, there is an effect of the stress waves arising during the detonation pressure that destroys both the ore and the backfill mass.

The stress-strain state of rock reduces in the vicinity to the backfill mass. Further away from the backfilled stope, the stress-strain state of the rock increases and reaches its maximum value and then comes down to its natural stress-strain state, and then increases again in the proximity to the drilling drift.

Table 2 - Recommended mixture compositions

Mixture code	Specific consumptions, kg/m3							Mixture density, kg/m3	Cube strength		Estimated strength in the stope, R90, MPa
	Binder			Filler			Water		MPa		
	Total	including		Total	including				R28	R90	
		cement	lime		tailings	screenings					
M301	240	240	-	1240	-	1240	500	1990	1,1	2,85	3,7
M302	200	200	-	1280	-	1280	450	1980	0,76	1,9	2,5
M303	150	150	-	1310	-	1310	450	1980	0,4	1,1	1,5
M304	200	200	-	1330	1050	285	450	1985	1,3	3,5	4,0
M305	150	150	-	1350	650	700	450	1980	1,5	3,4	3,8
M306	150	150	-	1330	1350	-	500	1980	0,85	1,8	2,3
M307	120	120		1350	1350	-	500	1985	0,4	0,95	1,25
M308	170	160	50	1250	1250	-	550	1990	1,2	3,0	3,8
M309	150	180	70	1280	1280	-	580	1990	1,0	2,4	3,1
M310	170	120	50	1310	-	1310	550	1985	1,25	2,75	3,5
M311	140	480	60	1310	-	1310	550	1985	0,65	1,7	2,1
M312	170	120	50	1300	950	350	550	1980	1,15	3,0	3,3
M313	140	170	70	1350	650	600	550	1980	0,6	1,75	2,2
M314	170	80	90	1350	600	650	550	1980	0,9	2,5	2,85
M315	220	100	120	1250	1250	-	550	1990	1,2	3,4	4,2

In order to determine the stress distribution along the drill holes placed in the direction of action of the mean stress, computer modelling was conducted using Examine2D software (Figure 5).

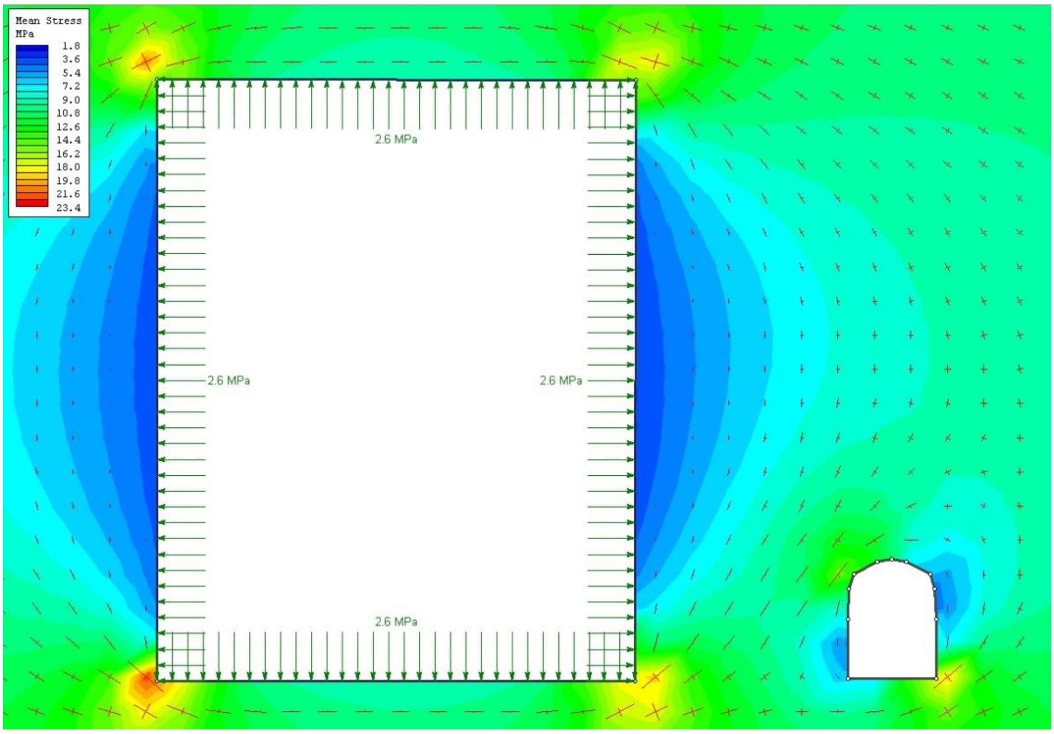


Figure 5 - Stresses around the stope and a drilling drift

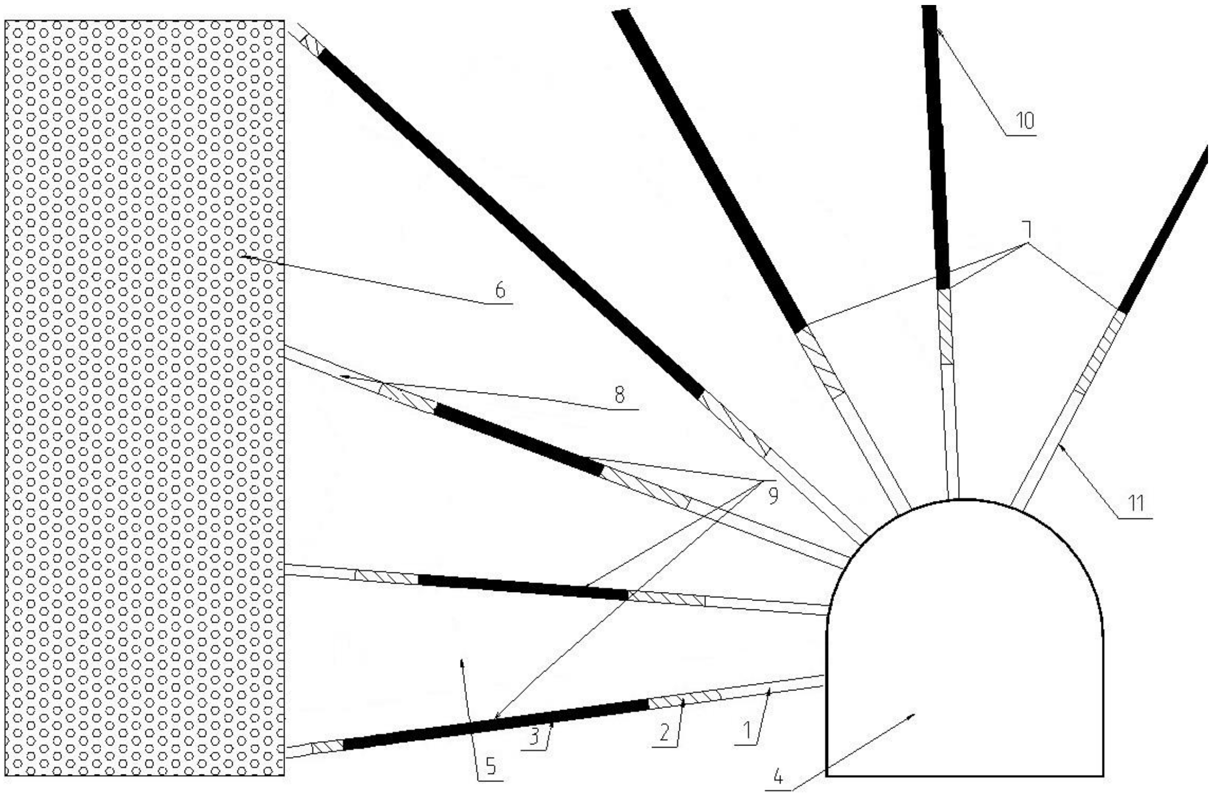
Figure 5 reflects mean stresses (discharge area) of the second stage stopes after the first stages stope has been backfilled for the conditions of Maikain mine. As can be seen, lower stresses around the second stage stope are in its middle part, and maximum stresses are at the upper and lower corners of the first stage stope.

As a results, it can be concluded that the undercharge portion of some ring drill holes in their bottom can be determined according to the length of the discharge zone.

A layer of the backfill mass is in the most severe conditions at the contact with the ore. In the process of mining of ore reserves, the contact layer withstands the maximum loads from blasting, and after blasting, when it is left open, there is also a load (pressure) from the rock and the backfill mass itself. The effect of blasting in these specific conditions is usually reflected in the form of rockfalls, falls of the concrete backfill, which as consequence increases dilution of ore, and leads to increased mining safety risks.

As a result, it was determined that the distribution of vertical stresses along the drill hole located in the direction of the action of the minimum principal stress. Considering this fact and to reduce the dilution of ore, an uncharged part of blast holes in the ring was increased in their bottom portion for the length of the destressed zone.

Figure 6 represents blast holes and the explosive distribution in them.



1 - unloading zone; 2 - zone of stress concentrations; 3 - ore zone; 4-drilling drift; 5 - ore body; 6 - backfill mass; 7 – blast holes; 8 - blast hole oriented in the direction of the minimum stress; 9 – blast holes in contact with the backfilled stope; 10 - undercharged portions of blast holes in their bottom parts; 11 - undercharged portions of blast holes in their collar parts.

Figure 6 - The circuit arrangement of wells and placing them BB

Obtained results can be represented as a diagram in the figure 7.

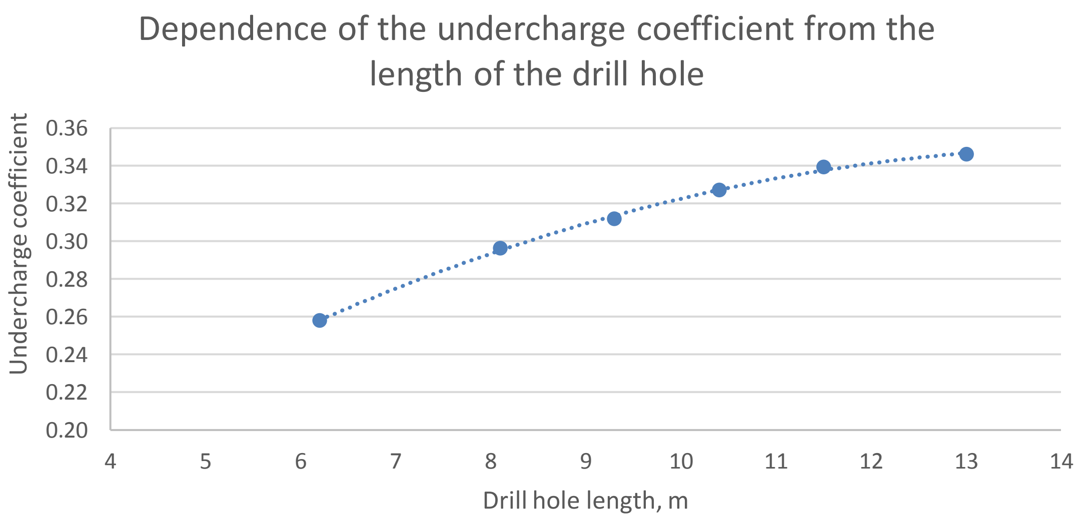


Figure 7 - Dependence of the undercharge coefficient of the drill holes in the direction of the backfilled stope from their length

Statistic interpretation of the dependence of the undercharge coefficient of the drill holes from their length resulted in the formula:

$$\text{Кнед} = -0.0013 \times L\text{скв}^2 + 0.04 \times L\text{скв} + 0.07$$
$$6 < L\text{скв} < 13)$$

where Lскв – drill hole length, m,
Кнед – total undercharge (.

The proposed technology must perform the following sequence:

Using the data, including physical and mechanical properties of the ore and the surrounding rocks, depth of the stopes and their parameters, parameters of the drill drift, and the stresses around the drift and the stopes. Given the fact that the discharge zone is 0.2-0.25 of the value of the normal stress zone, the length of the undercharge can be determined at the bottom parts of the drill holes.

Thus, determination of the length of the discharge zone considering the stress-strain state allows to reduce the specific consumption of explosives, losses and dilution of ore with the backfill material.

Expected economic effect from the use of the proposed technology is calculated considering reduction of ore dilution with the filling mixture during the blasting procedures at the ore-backfill contact, decrease of the cement consumption due to addition of the plasticizers and additional costs for the purchase of such plasticizers is 29.8 mln. tenge on annual production volume.

This paper gives a solution to the critical problem of mining of ore reserves below the pit and in the pit walls for the mines with combined (open-pit-underground) mining.

As a result of the research work, the following conclusions can be drawn:

1. The analysis of international experience of mining of ore reserves below the pit and in the pit walls leads to the conclusion that for Maikain mine conditions effective way of mining such ore is proposed using stoping mining methods with backfill in several stages with different strength for every stage.

2. Installed nominal strength of backfill is based on the stage of the stope. The required strength of the backfill for the Maikain mine conditions:

- Stopes of the first stage - 2.6 MPa;
- Stopes of the first stage - 3.0 MPa;
- Stopes of the first stage - 4.25 MPa.

3. Strength of the backfilled stope depends of the vertical exposure and the stage of the stope. For example, vertical the stopes with the height from 5 m to 40 m, the strength of the filling mass varies from 1.2 MPa to 4.0 MPa.

4. For filling mixtures, in order to provide the necessary flexibility and strength of the filling mass for the Maikain mine conditions, as a filler, it is appropriate to use local flotation tailings and screenings of the crusher, and as a binder portland cement and lime.

5. It was established that addition of the plasticizers in the mixture, such as Pozzolith MR 55 at a dosage of 1.0 l/m^3 of the filling mixture improves mobility by 20% and improves strength of the backfill by 12-15%.

6. Developed technology of mining of the reserves below the pit bottom and in the pit walls, provides a more complete extraction of reserves, safe and efficient mining operations.

7. Blasting technology at contact with the filling mass was proposed considering the discharge zone. Portions of the blast holes directed to the filled stopes in their bottom part can be undercharged to the length equal to the discharge zone. For example, for the blastholes with the length from 6m to 13m, the length of the undercharge should be from 0.4 m to 1.0 m.

8. The estimated economic effect of the proposed technology and technical solutions is 29.8 million tenge on the annual basis.

The main results of research on the thesis are published in the following works:

1. Krupnik L.A., Yusupov Kh.A., Aben Kh.Kh. The gold market: state and prospects, Mining Journal of Kazakhstan, 2016, No. 1, p.5-9.

2. Aben Kh.Kh. Formation of filling material taking into account changes in its properties, International Conference "Innovative development of the mining industry", Krivoy Rog, 2016, p.101.

3. Krupnik L.A., Aben Kh.Kh. The technology of mining of the reserves under the pit and in the pit walls of the Maikain "B" deposit, Collection of the International XV Baikonur Readings, Zhezkazgan, 2015, p.53-55.

4. Aben Kh.Kh., Yusupova B.R. Normative strength of the backfill for the conditions of the Maikain mine, Proceedings of the International Satpaev Readings, Almaty, 2017, p.496-500.

5. Aben Kh. Effect of chemical additives-plasticizers on the properties of backfill, Mining Journal of Kazakhstan, 2018, №2, p.14-16.

6. Bitimbaev M. Zh., Krupnik L.A., Aben Kh.Kh., Aben E. Kh., Selection of the composition of the back-filling mixture for mining of the reserves under the pit, Scopus, Moscow, 2017, No. 2, p. 57-61.

7. Krupnik L.A., Aben Kh.Kh., Myrzakhmetov S.S., Yusupova B.R. Ore blasting at the contact with the backfilled stopes, Explosives, IPCON RAS, Moscow, 2017, p.205-213.

8. Aben Kh., Krupnik L.A., Shaposhnik Y.N. Technology of blasting at the contact with backfilled stopes, Mining Journal of Kazakhstan, 2017, No. 11, p.4-5.